INDOOR MICROCLIMATE OF A PRESERVED MOUNTAIN VILLAGE DWELLING IN THE ORE MOUNTAINS: A CASE STUDY

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Abstract

Preserved village dwellings provide a satisfactory indoor microclimate when an appropriate building use regime is applied. Using eight dataloggers, we monitored the indoor environment in a case study of a mountain dwelling built in 1911 in Bublava, located in the Ore Mountains, over one week during the summer and autumn. The results show that this case study house, largely preserved in its original state of construction, has an effective use regime and is highly adaptable to different weather conditions.

Keywords

Indoor microclimate, village dwelling, use regime, relative humidity, carbon dioxide

1 INTRODUCTION

This study aims to prove that preserved village dwellings in the original state of construction can offer satisfactory indoor microclimate without the need for building modifications. A good indoor microclimate in historical buildings conflicts with energy efficiency requirements. Buildings are being insulated and sealed to prevent any air leakage, which worsens the indoor microclimate conditions and leads to the loss of their valuable architectural expression.

We hypothesize that satisfactory indoor microclimate conditions can be achieved in historical buildings by implementing appropriate use regimes, without the need for modern building modifications. The indoor microclimate is extensively studied in public buildings and in the design of optimal HVAC settings. We address a gap in scientific knowledge by presenting field monitoring results from historic village buildings. By monitoring selected case studies, we will be able to propose a passive solution for improving the interior microclimate of historical village dwellings by setting satisfactory use regime, while maintaining their valuable architectural expression. In a wider context, this research is important for the protection of cultural heritage as well as the protection of the health of the building's occupants.

The importance of maintaining a healthy indoor microclimate is well documented. For instance, Zmrhal et al. reported in 2011 increasing concentrations of carbon dioxide (hereinafter referred to as "CO_2“) in interiors due to sealing of joints in buildings [1]. The authors also drew attention to increasing the concentrations of VOC (Volatile Organic Compounds) such as formaldehyde. The maximum allowed limit of CO_2 concentration in the interior decreased from 1500 ppm to 1200 ppm in 2024 with the issuance of a new decree on building requirements [2]. Furthermore, the presence of dampness in buildings increases the risk of mould growth, which can damage the structure, according to Zvěřinová Mlejnková [3]. Hurraß et al. state that mould can harm the health of occupants with long-term exposure [4]. The authors link the occurrence of moulds to the following diseases: allergic respiratory diseases, asthma, allergic rhinitis, hypersensitivity pneumonitis, possible respiratory tract infections, and bronchitis. The authors recommend maintaining an indoor air temperature of around 20 °C and keeping the relative humidity (hereinafter referred to as "RH") below 65%.

Another concern in historical buildings is radon exposure, particularly in areas like the Ore Mountains. Al-Zoughool et al. identify radon as a known lung carcinogen [5]. The reference limit for indoor radiation exposure is 300 Bq/m³ as specified in § 97(1)(a) of Decree No. 422/2016 Coll. [6]. According to the results of the state programme for identifying buildings with elevated radon levels conducted in Bublava between 1981 and 2009, out of a total of thirty buildings, six had radon concentrations exceeding 400 Bq/m³, and one even exceeded

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1000 Bq/m³ [7]. To reduce the concentration of radon in the existing building, several technical measures can be implemented. However, according to Jiránek, a mere increase in the intensity of ventilation will naturally reduce the radon concentration by 20% to 40% [8].

We used a method of a field measurement study in the Kraslice region where valuable historical mountain village dwellings are preserved. These detached family houses, built with log construction, half-timbering, or exposed clinker brick masonry, are not legally protected but are recognized for their valuable architectural expression [9], [10], [11]. For the case study, we selected a building with a load-bearing construction made of exposed clinker bricks, which is diffusely open and enables the transfer of dampness according to Feilden [12]. Insulating the façade of this building is undesirable as it would lead to a loss of its valuable architectural expression.

Our methodology builds on established approaches for indoor microclimate monitoring using dataloggers, as exemplified by Widera's research on traditional sub-Saharan dwellings [13]. In addition to monitoring the main living rooms, we included monitoring of adjacent non-living rooms to determine the complex behaviour of the indoor microclimate throughout the building. This method allows us to identify how the building's use regime influences the quality of the indoor environment and provides insights into passive measures for improvement.

2 METHODOLOGY

Case study house description

The case study house, built in 1911 for Gustav Seifert and designed by master builder Emanuel Gemeinhardt from Kraslice, serves as a family residence [14], (Fig. 1). It is a two-story house with a basement under approximately one-third of a ground plan.

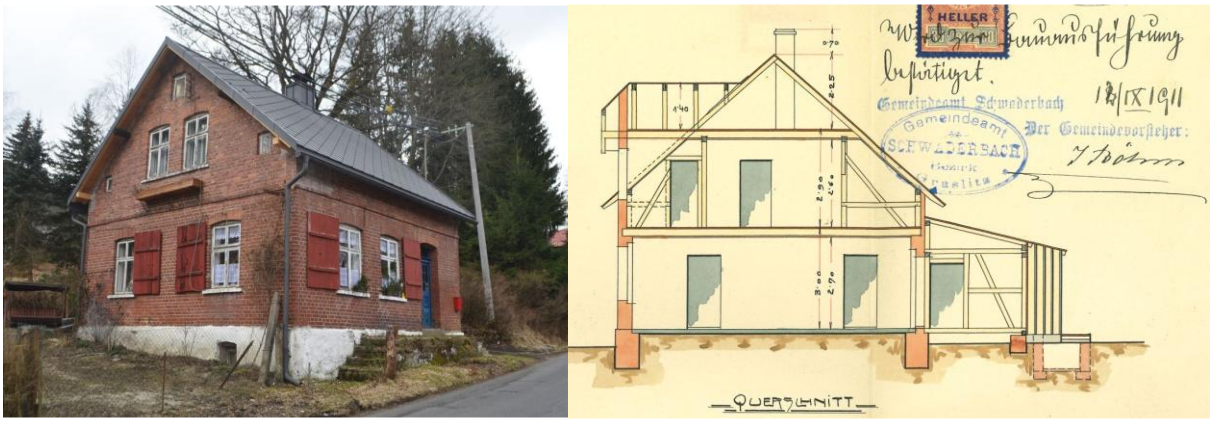

Fig. 1 The view of the case study building in 2024 from the south-east (left). The section of the case study house on the original building plan (right). The house was originally designed without basement and with a dormer which remained unrealised [14].

The foundations consist of stones laid with clay mortar. The load-bearing structure is made of exposed masonry of German format using clinker bricks. The ceiling between the first and second floor is timbered with a plastered reed underlay. The ceiling between the basement and the ground floor consists of three fields of brick vaults supported by steel beams. The floor in the living room and the kitchen is made of wide wooden planks nailed to the support beams laid on the ground. In the hallway on the ground floor, there is a floor made of cement tiles laid directly on the ground. The floor on the second floor consists of planks nailed directly to the ceiling beams. The staircase to the upper floor is made of solid wooden boards. The roof is supported by a truss with purlins in the middle of the span of rafters. The roofing is partially reconstructed and consists of wooden planks covered by modern waterproofing foil covered with modern aluminium shingles. The living rooms on the second floor are separated from the remaining attic space by masonry partitions located under the purlins, and by a ceiling at the level of the purlins. The ceiling consists of wooden beams covered with wooden planks underneath with a reed underlay and lime plaster. Apart from the roofing, the constructions are original from the time of construction of the building in 1911. The doors are original wooden framed doors with a wooden panel or glass

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inserts. The windows in the living rooms are wooden casement windows with double frames. The windows in the unoccupied spaces are simple wooden single-frame windows.

Monitoring method

We conducted indoor microclimate monitoring over one week in two different seasons. The first monitoring took place from 15/7/2024 to 21/7/2024 during extremely hot summer conditions that exceeded average summer temperature between 15 °C to 16 °C according to Tolasz [15]. The recording interval was set for 1 minute. The second monitoring was conducted between 21/10/2024 and 28/10/2024 during autumn, which corresponded with common autumn weather temperatures of 6 °C to 7 °C [15]. The recording interval was set for 5 minutes.

We used mobile dataloggers for the monitoring. We placed each datalogger in a different room in the case study building. The positions of dataloggers are presented in Fig. 2. The positioning of dataloggers was limited by the case study house being used by its inhabitants. The ideal positioning of dataloggers in the middle of the room at a height of 1 meter was not always achievable. We positioned the dataloggers as close to the ideal locations as possible without disturbing the residents.

Fig. 2 The plans of the case study house with positions of dataloggers. Dataloggers U3430 were used in the living areas (A – living room, B – bedroom). Dataloggers U3120 were used in unoccupied rooms (C – basement, D – corridor on the ground floor, E – chamber under the roof, F – corridor on the second floor, G – attic, H – outside).

We used six Comet U3120 dataloggers to monitor RH and air temperature and two Comet U3430 dataloggers to monitor RH, air temperature, and CO_2 concentration. The LCD displays of the dataloggers were turned off during monitoring so that the inhabitants did not influence the results by knowledge of the parameters. We collected the data from dataloggers after the monitoring was finished and evaluated the results in the Comet Vision Software. The calibration sheets of the data loggers indicate the following measurement uncertainties: temperature ±0.4 °C, relative humidity ±1.8 %, CO_2 concentration ±50 ppm.

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Microclimate conditions of surroundings

The building is located near a north-south main asphalt road in the valley at 660 meters above sea level. It is shaded in the early morning by the hill on the east and in the evening by the hill on the west. In the neighbourhood, there are detached houses with gardens. The house is surrounded by a garden with grass, trees, and a large sycamore maple to the northwest, which shades the house in the evening. To the north, there is a one-story garage.

Use regime

The building serves as a family house and is inhabited by two occupants, a dog and a cat. Male, retired, 60+, and female, productive age, 50+. The research participants were asked to describe their daily routine and habits of using the space at the end of each weekly monitoring.

The living room and bedroom are heated by local heaters – stoves. The unoccupied spaces are not heated. The building is naturally ventilated through the windows. Due to the presence of the original opening fillings, which are not tight, air infiltration occurs even when all windows and doors are closed.

In the summer period, both occupants were off work and spent their vacations at the house. They often alternated between staying in the house and the garden. In each living area, a window was opened with an insect net installed.

In the autumn period, one of the occupants went to work in the afternoons from Monday to Friday, while the other stayed at the house. In the morning, the occupants lit the stoves in the living room and kept the stoves warm until the evening hours. In the evening, the occupants lit the stoves in the bedroom and kept it warm until they fell asleep. The occupants ventilated the interior by occasional opening of the window.

3 RESULTS

The result section presents the values recorded during the monitoring in the summer season from Monday 15/7/2024 0:00 to Monday 22/7/2024 0:00 and in the autumn season from Monday 21/10/2024 0:00 to Monday 28/10/2024 0:00. This section is divided into three subsections accordingly to the parameter monitored.

Air temperature

For the air temperature monitored in July 2024 refer to Fig. 3 and for the air temperature monitored in October 2024 refer to Fig. 4. Measured minimums, maximums, and average air temperature are described in Tab. 1.

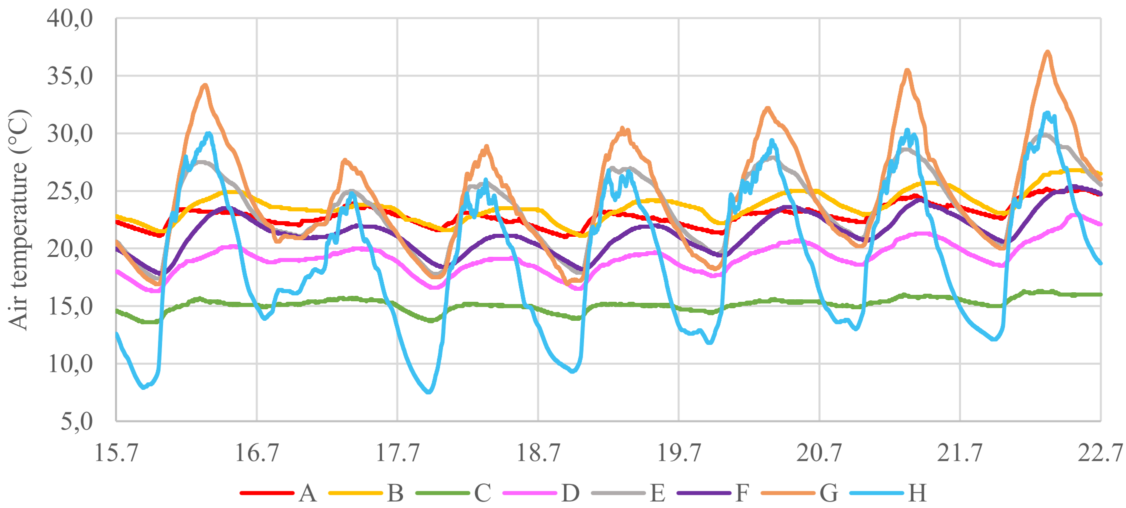

Fig. 3 The air temperature data from Monday 15/7/2024 0:00 to Monday 22/7/2024 0:00. Refer to Fig. 2 in the methodology section for the curve labels (A to H).

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July monitoring revealed that all interior spaces are dependent on changes in the exterior air temperature. The interior spaces were not artificially tempered or cooled during the monitoring in July. Differences between day and night outdoor temperatures reached up to 20 °C on some days. The most stable air temperature was monitored in the basement (C) ranging from a minimum of 13.6 °C to a maximum of 16.3 °C. The highest recorded air temperature was monitored in the attic (G) with a maximum of 37.1 °C, which is 5.3 °C above the outdoor maximum. In the living room, (A) the air temperature ranged from a minimum of 21.0 °C to a maximum of 25.2 °C and in the bedroom (B) ranged from a minimum of 21.1 °C to a maximum of 26.8 °C.

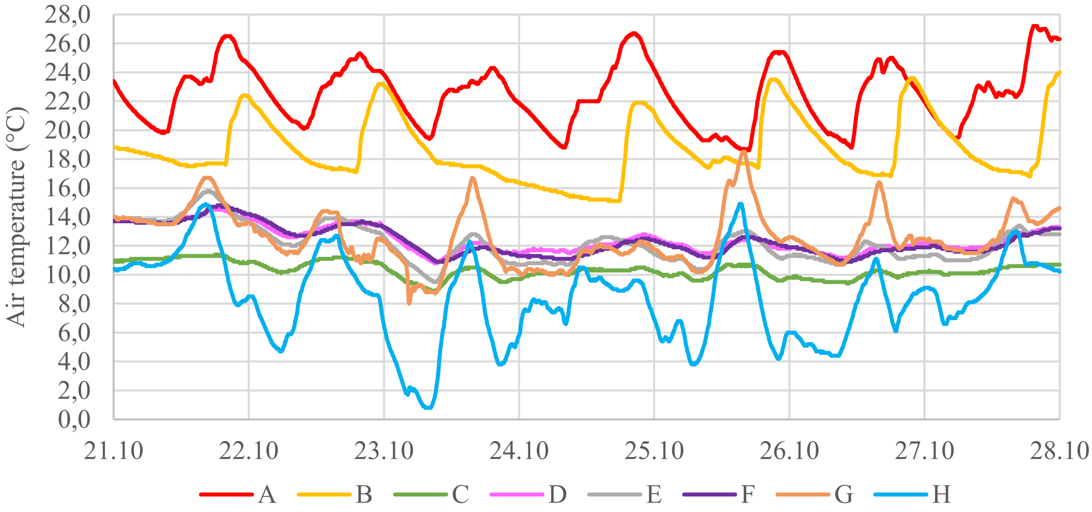

Fig. 4 The air temperature data from Monday 21/10/2024 0:00 to Monday 28/10/2024 0:00. Refer to Fig. 2 in the methodology section for the curve labels (A to H).

October monitoring demonstrates the impact of heating with local heaters in the form of wood stoves in the living room (A) and the bedroom (B). Curves A and B rise steeply when the heating of the room starts and slowly decline as the heating is stopped. The average air temperature in the living room (A) was 22.5 °C ranging from a minimum of 18.6 °C to a maximum of 27.2 °C. The average air temperature in bedroom (B) was 18.7 °C ranging from a minimum of 15.1 °C to a maximum of 24 °C. Unoccupied spaces maintained a stable average temperature of approximately 12.2 °C, with an exception in the basement (C) where the coolest air temperature was recorded with an average of 10.3 °C.

Tab. 1 Recorded air temperature values for each datalogger during the July and October periods. Letters A to H correspond to different dataloggers positioned in various rooms. Refer to Fig. 2 in the methodology section for dataloggers positions.

	July T (°C) min.	**July T (°C) max.**	**July T (°C) average**	**October T (°C) min.**	**October T (°C) max.**	**October T (°C) average**
A	21.0	25.2	22.9	18.6	27.2	22.5
B	21.1	26.8	23.7	15.1	24.0	18.7
C	13.6	16.3	15.1	8.9	11.4	10.3
D	16.3	22.9	19.2	10.8	14.6	12.4
E	17.4	29.9	23.6	9.5	15.8	12.2
F	17.8	25.4	21.4	10.9	14.8	12.3
G	16.9	37.1	24.6	8.0	18.5	12.5
H	7.5	31.8	19.3	0.8	14.9	8.4

DOI 10.13164/juniorstav.2025.25054

Air relative humidity

For RH monitored in July 2024 refer to Fig. 5 and for RH monitored in October 2024 refer to Fig. 6. Recorded minimum, maximum, and average air temperature are described in Tab. 2.

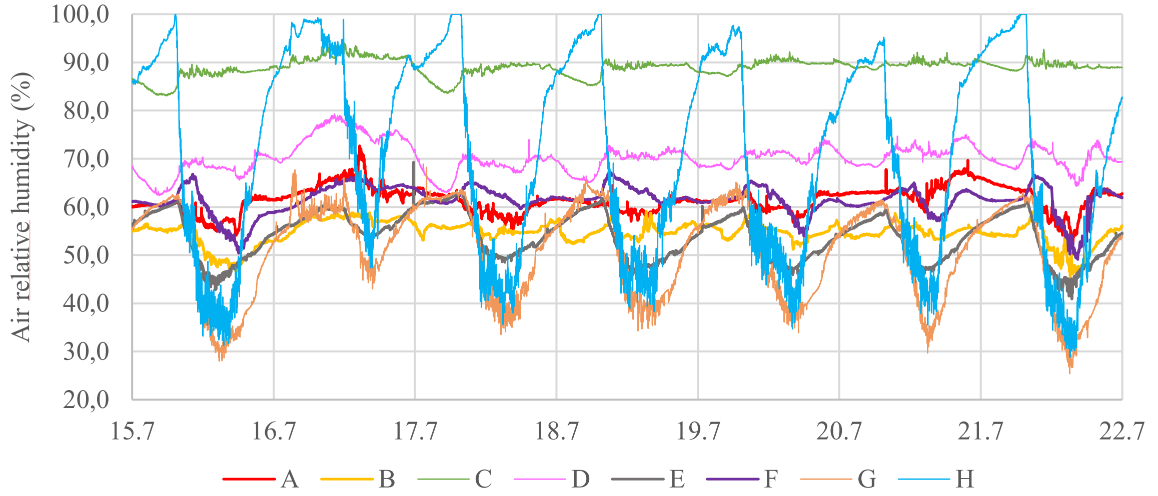

Fig. 5 The air relative humidity data from Monday 15/7/2024 0:00 to Monday 22/7/2024 0:00. Refer to Fig. 2 in the methodology section for the curve labels (A to H).

During the summer period, the outdoor RH was low during the daytime and reached the weekly minimum of 28.8%. In the morning hours, it reached a maximum saturation of 100% on some days, which manifested as morning dew. In the interior, the highest RH was recorded in the basement with an average of 88.9%. In the other interior spaces, both living and unoccupied, the RH recorded between 50 and 70%. The lowest RH was recorded in the attic (G) with a minimum of 25.4%.

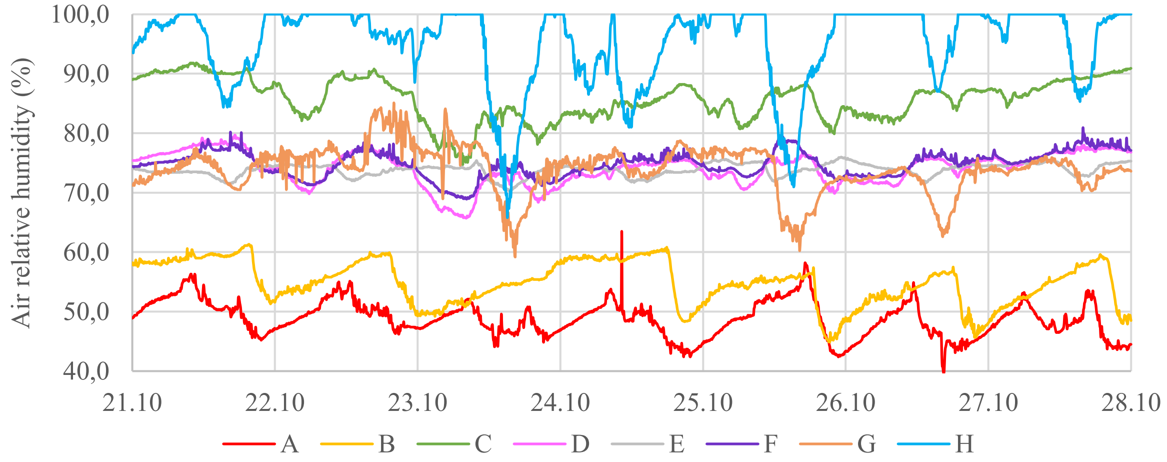

Fig. 6 The air relative humidity data from Monday 21/10/2024 0:00 to Monday 28/10/2024 0:00. Refer to Fig. 2 in the methodology section for the curve labels (A to H).

During the autumn period, the outdoor RH was high (H). It reached an average of 95.2%. In the morning and daytime, it reached a maximum saturation of 100%, which manifested itself as mist. The heating of the interior spaces (A – living room, B – bedroom) had the effect of lowering RH. In the living room (A), it reached an average of 48.8% and in the bedroom, it reached an average of 54.8%. Among the other unoccupied rooms, the highest RH was recorded in the basement where it reached an average of 85.8%. In the other unoccupied rooms, RH was recorded steady at around 74%.

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Tab. 2 Recorded air relative humidity values [%] for each datalogger during the July and October periods. Letters A to H correspond to different dataloggers positioned in various rooms. Refer to Fig. 2 in the methodology section for datalogger positions.

	July RH (%) min.	**July RH (%) max.**	**July RH (%) average**	**October RH (%) min.**	**October RH (%) max.**	**October RH (%) average**
A	51.8	72.7	61.5	39.6	63.6	48.8
B	45.3	59.8	54.7	44.9	61.3	54.8
C	83.1	94.0	88.9	74.7	91.8	85.8
D	62.4	79.3	70.1	65.7	79.7	74.1
E	40.9	69.3	53.9	70.3	76.0	73.8
F	49.1	67.2	61.4	68.9	80.9	74.8
G	25.4	68.2	51.1	59.2	85.1	74.0
H	28.8	100.0	71.8	65.8	100.0	95.2

Carbon dioxide concentration

For the CO_2 concentration monitored in July 2024 refer to Fig. 7 and for the CO_2 concentration monitored in October 2024 refer to Fig. 8. Recorded minimum, maximum, and median values are described in Tab. 3.

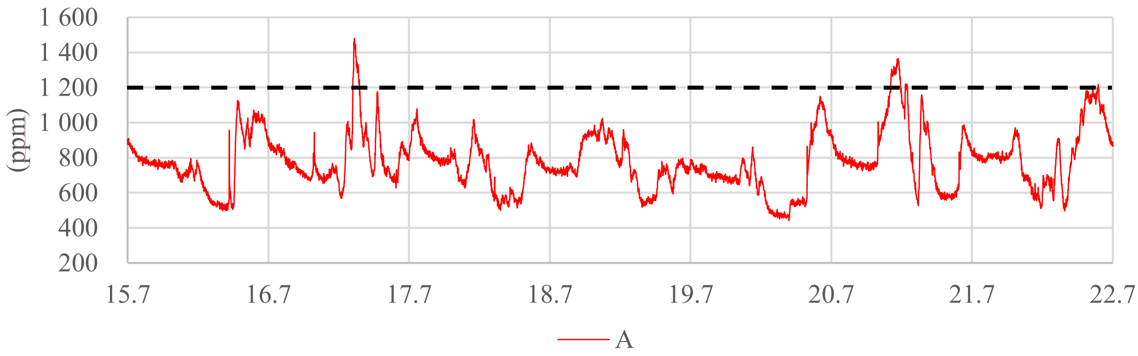

Fig. 7 The CO_2 concentration data from Monday 15/7/2024 0:00 to Monday 22/7/2024 0:00 recorded in the living room (A).

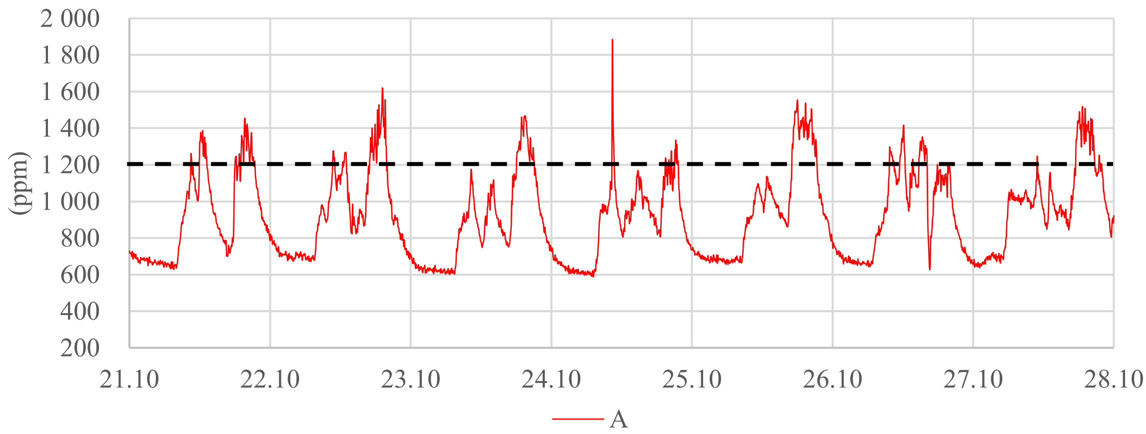

Fig. 8 The CO_2 concentration from Monday 21/10/2024 0:00 to Monday 28/10/2024 0:00 recorded in the living room (A).

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During the monitoring in the summer period, the CO_2 concentration was satisfactory.In the living room (A), the CO_2 concentration was at an average of 779 ppm. It exceeded the threshold of 1200 ppm occasionally for a brief time.

During the autumn, the CO_2 concentration exceeded the maximum of 1200 ppm in the living room (A) repeatedly every afternoon [2]. On 24/10/2024, the maximum of 1871 ppm was reached. This value was recorded only in one 5-minute record interval and the exceptionally high air relative humidity was monitored at the same time. This could have been caused by a smoke leakage during the lighting of the stove.

The CO_2 concentration in the living room (A) increases in the morning when occupants are present, and during the day decreases when the space is unoccupied or a window is deliberately opened, and the air is ventilated. During the night, the CO_2 concentration decreases to a minimum of around 600 ppm.

The CO_2 concentration was also recorded in the bedroom (B). However, after the measurement, we found out that the bedroom datalogger's CO_2 sensor was faulty. Therefore, the corresponding data were excluded from the results due to their unreliability.

Tab. 3 Recorded CO_2 concentration for each datalogger during the July and October periods. Letters A to H correspond to different dataloggers positioned in various rooms. Refer to Fig. 3 in the methodology section for datalogger positions.

	July (ppm) min.	**July (ppm) max.**	**July (ppm) average**	**October (ppm) min.**	**October (ppm) max.**	**October (ppm) average**
A	442	1479	779	588	1871	919

4 DISCUSSION

The monitoring of indoor microclimate in the case study house shows that the building has a high ability to prevent the interior from overheating thanks to its load-bearing construction made of clinker bricks. In the summer period, the temperature in the living room maintained comfortable values between 21 °C and 25.2 °C, despite outdoor temperatures fluctuating by approximately 20 °C within 24-hour periods, with a maximum of 31,8 °C recorded (Fig, 3, Tab. 1).

In autumn, the use regime changed with the start of the heating season. The heating of living areas (living room A, bedroom B) affects the air temperature of heated spaces significantly, while unoccupied and unheated spaces (C to G) remain more dependent on outdoor temperatures (H). In unheated spaces, nighttime air temperatures dropped by 2–4 °C, whereas the outdoor air temperature decreased by over 10 °C (Fig. 4, Tab. 1). That highlights the high ability of clinker brick masonry to accumulate heat.

The original design of the bedroom (B), separated from the attic by partitions and a ceiling, creates an insulating air volume in the attic (Fig. 1). During summer, the temperature in the bedroom (B) did not exceed 26.8 °C, despite outdoor temperatures reaching a maximum of 31.8 °C (Tab.1). Adjacent unoccupied spaces, such as the attic (G) with a maximum temperature of 37.1 °C recorded, and the storage room under the roof (E) with a maximum of 29.9 °C recorded, contribute to preventing the bedroom from overheating.

The outdoor RH was higher in the autumn, averaging 95.2 %, compared to an average of 71.8% in the summer (Tab. 2). In the autumn, all unoccupied spaces recorded an average RH above 73%. This value poses a risk for mould growth. The mould growth and degradation of hygroscopic materials (i.e. cardboard box) were observed in the basement where an average of 88.9% RH was recorded in the summer and an average of 85.8 % was recorded in the autumn. The presence of mould in other interior spaces was not recorded during the building technical survey, and the research participants did not report problems with mould growth either. The likely reason is the low air temperature for mould growth (recorded average of 12.2 °C to 12.4 °C in rooms D to G), combined with the air circulation caused by air leakage through leaky joints of building openings (Tab. 1).

The RH in the living room (A) and the bedroom (B) was lower in the autumn due to the heating of the space (Tab. 2). In the summer, an average of 61.5% was recorded. The maximum of 72.7% was recorded on 16/7/2024 when it was rainy outside. The RH does not exceed the recommended maximum of 65% [4] in the long-term in the living room (A), which would indicate a risk for mould growth (Fig. 6). The mould growth in the living room was not reported by the research participants either. In the autumn, an average of 48.8% RH was recorded. The RH

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in the living rooms (A, B) did not exceed the recommended threshold of 40% and 65% in the long term and shows good living conditions. (Fig. 5, Fig. 6, Tab. 2).

An average CO_2 concentration of 779 ppm was recorded in the living room (A) during the summer and 919 ppm in the autumn (Tab. 3). These values indicate a satisfactory indoor microclimate. For short periods, the 1200 ppm threshold was exceeded repeatedly in the afternoon in the living room (A) during autumn (Fig. 8). The lower values for CO_2 concentrations in the summer can be explained by interior spaces being permanently ventilated by opened small windows fitted with an insect net (Fig. 7). The values of average CO_2 concentration were 15% higher in the autumn period. This can be explained by the more frequent presence of occupants in the interior of the living room (A). In the autumn, a noticeable decrease in CO_2 concentration occurs in the living room whenever it is unoccupied (Fig. 8). This effect can be explained by natural ventilation through leaks in window and door joints, enhanced by the stack effect as the stoves heat the spaces.

Radon exposure was not recorded as it was already monitored for Bublava village in the study State Program for Identifying Buildings with Elevated Radon Levels [7]. The presence of radon in the house is expected and it is advised to the research participants to increase air exchange and in case of ground floor replacement, carry out radon insulation.

5 CONCLUSION

The study provides comprehensive insights into the indoor microclimate of the case study house.

- The load-bearing structure made of clinker bricks effectively prevents overheating in the summer and excessive cooling in autumn by accumulating heat,
- The air volume in unoccupied attic spaces adjacent to the bedroom acts as thermal insulation and prevents the bedroom from overheating in the summer and losing heat in the autumn,
- The RH median ranged from 48.8 to 61.5% in the living areas, which is satisfactory for the occupants,
- The RH exceeded the threshold of 70% only exceptionally in the summer for a short period,
- The RH median exceeded the threshold of 70% in the unoccupied rooms and exceeded the threshold of 80% in the basement, which poses a risk for mould growth,
- Research participants were advised to monitor for the occurrence of mould growth in rooms exceeding 70% RH,
- In the living room (A), the CO_2 concentration exceeded the threshold of 1200 ppm only exceptionally for a brief time in the summer, but in the autumn period it repeatedly exceeded the threshold of 1200 ppm every afternoon. This parameter could be improved by increasing the air exchange rate.

The results largely met expectations, confirming that the case study house provides a good indoor microclimate, although some parameters exceptionally exceeded recommended limits. The contemporary use regime of the case study house is satisfactory. The building's construction continues to offer a suitable indoor environment without the need for modifications, even after 114 years.

The case study house will be monitored in the winter and spring to gain information on a full annual cycle. In the following steps of the study, other case study buildings of the same typology and the same location with different use regimes will be monitored and the results will be compared. The goal is to find an optimal use regime for the typology of these buildings without the need for building modifications.

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